Designing a seamless learning environment to learn reduce, reuse and recycle in environmental education

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Abstract: This article explores the design of a seamless learning environment and activities for environmental education using mobile, wireless, and online technologies in Singapore primary schools. The learning environment and activities were designed to help students learn about environmental issues, specifically reduce, reuse and recycle (3Rs), and apply such understanding to practice. By seamless, we mean the transitions between classroom learning and field learning, between handheld use in the field and desktop computing back in the school. The research results indicated improvements in the students’ understanding of the 3Rs and internalisation of their understanding through application of the 3Rs concepts.

Keywords: environmental education; mobile learning; 3Rs; reduce, reuse and recycle; seamless learning.


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BaoHui Zhang is an Assistant Professor at the Learning Sciences and Technologies Academic Group and a Faculty Researcher at the Learning Sciences Lab. He started his career as a high school chemistry teacher. Later, he became a Teacher Educator and Education Researcher in applying educational technologies for learning purposes. He has published a number of journal papers in both Chinese and English. In addition, he has presented his research done in China, USA and Singapore during conferences and invited academic exchange trips. His current research foci are computer-based modelling and science learning and using mobile technologies for inquiry-based science learning.

Wenli Chen is an Assistant Professor in Learning Sciences and Technologies Academic Group and a Faculty Researcher in the Learning Sciences Lab, National Institute of Education. She has contributed to a number of research projects in the fields of education and communication. Her current research foci are computer-mediated communication, virtual learning environment, community of learners and mobile learning.

Chee-Kit Looi is Head of the Learning Sciences Lab (LSL) of the National Institute of Education (NIE). He has over two decades of experience with educational technology research in research institutes and universities. His research has resulted in learning environments used by Singapore and South-East Asian students and educational software licensed to local industry; he is an Editorial Member of the *International Journal on AI and Education* and the *International Journal on CSCL*.

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### 1 Introduction

There is a growing global concern about the environment we live in. As countries become more industrialised, the amount of waste generated has sparked awareness on how excessive waste can harm our environment. In Singapore, the National Environment Agency (NEA) works closely with the schools to educate school children about the need to conserve the environment. Activities such as setting up green clubs in schools, poster exhibitions on the environment and recycling competitions are organised to create awareness about the environmental issues. Nevertheless, how to engage the students to learn about the environment and apply their understanding in practical ways at home is still a challenge.

In 2006, the Learning Sciences Lab at National Institute of Education Singapore collaborated with six Singapore primary schools and Temasek Polytechnic in designing and developing learning activities that would enable Primary 4 students learn about the reduce, reuse and recycle (3Rs) with the support of mobile technologies. The software and lessons were designed collectively by teachers and researchers. In addition, Temasek Polytechnic collaborated on the design of the software and developed a customised
application for the mobile device integrated with a camera. The application on the mobile
device allowed students to seamlessly transfer data from it to the online forum over a
wireless network. About 480 students from the six schools participated in the project
which spanned over two weeks. In this article, we present our design-based research
(Barab, 2006) study which explored the design of a seamless learning environment (SLE)
and activities for pupils’ environmental education by using mobile, wireless and online
technologies. It is part of an ongoing research on how we can effectively design a SLE
using mobile and online technologies for environmental and science education.

2 Research study

Our hypothesis was that students who participated in the designed activities and learning
environment would acquire better understanding of the 3R concepts. This would enable
them to apply their understanding to their daily life. The following questions guided our
study:

1 How do we design a SLE that would help learners learn about environment issues
   and apply their understanding to their daily life?
2 What are the outcomes of student learning about the 3Rs in the SLE?
3 What are the areas for improvement in the design of the SLE?

To understand the effectiveness of our design, we conducted a study on 81 students from
one of the participating schools to evaluate what they had learned about the 3Rs and how
they had applied their understandings. Both quantitative and qualitative evaluation were
made through pre- and post-activity survey results, in-depth interviews, classroom
observations and studying student-created artefacts. We hope that the evaluation of our
study would also inform us of possible areas in improving the design of the learning
environment and activities.

Before the study, the researchers initiated the design of the learning environment
using seamless learning approach and the identified the use of a learning cycle to
structure student learning process. This setup the framework for the learning
environment. The design started from discussion between the researchers and a software
development team from Singapore Temasek Polytechnic to design and implement the
initial technology platform. Then, the researchers collaborated with the teachers in
designing the learning activities based on the learning cycle and seamless learning model
in regard to the technology development. In the iterative process of designing the activity,
modifications were made accordingly to the software design and the learning activity
design. Thus, teachers became co-designers of the software and learning environment as
well. Teachers as co-designers of the learning environment enabled the design decisions
to align with learning objectives, learning tasks and use of technology to engage the
learners more effectively (Foo, Ho and Hedberg, 2006). The researchers designed the
research plan together and they were non-participating observers in the classes studied.

3 Design approach

The objective of the lesson activity was to enable the students to understand the concepts
of the 3Rs and internalise their understanding by applying 3Rs in practical ways at home
and school. In designing the learning activities and learning environment, the approach was to let the pupils learn through activities within a meaningful context inside and outside the boundaries of the classroom. Some of the activities were mediated through the use of technology such as the mobile devices, wireless and online technologies, which can be used to facilitate collaboration between pupils, create and move information over physical spaces and time. To achieve this, our design was based on a challenge-experiential learning approach.

### 3.1 Challenge-experiential learning cycle

Using a learning cycle provides a structure for the students to reflect their experiences (Fielding, 1994). Karplus and Thier (1967) proposed the use of learning cycles to help children move from concrete to abstract understanding in science education through a sequence of exploration, invention and discovery. Their approach has been extended by other researchers (e.g. Colburn and Clough, 1997; Marek and Cavallo, 1997) to include constructivist approaches and engaging prior knowledge of learners. Schwartz and his colleagues at Vanderbilt developed the STAR Legacy learning cycle using a challenge or scenario to engage learners to introduce the lesson or invite inquiry (Schwartz et al., 1999a). Kolb’s (1984) Experiential Learning cycle uses the experiences of a learner in an activity to create new knowledge. The experiential learning cycle starts with the experience phase where learners are exposed to the learning activity. In the subsequent phases, the learners share and reflect on their experience, generalise it to build new knowledge and apply the knowledge in practice.

Learning about the environment in Singapore schools is often shared in activities such as recycling bottles in schools, reusing plastic containers and exhibitions organised by the school’s environmental club or the NEA. Thus, children in Singapore schools may have some understanding or prior knowledge of what the 3Rs mean through participating in various environmental activities in schools. The learning cycle designed for this study was based on the Kolb’s experiential learning cycle because learners construct new knowledge through a transformation in their experience (Kolb, 1984). This may lead to a modification of their prior knowledge and application of knowledge in practice. In order to provide an authentic context for learning (Brown, Collins and Duguid, 1999), we started experiential learning cycle with a challenge phase. Students are given a scenario or an authentic problem to solve as a challenge. In addition, the challenge tests student prior knowledge. According to the book *How People Learn* (Bransford et al., 2000), engaged learning takes place when prior knowledge is challenged with the formation of knowledge in the learner. Using challenge as the beginning of the inquiry process, pupils learn by acquiring relevant information according their needs meet the challenge (Schwartz et al., 1999a).

The challenge-experiential cycle is shown in Figure 1. In the ‘Challenge’ phase, teacher presents the background of the lesson and the challenge to the pupils with questions addressing the concepts to learn. Pupils are asked to record their prior knowledge through answering questions like what they expect to see. In the ‘Experience’ phase, pupils do a set of activities in the context of the learning objectives. Examples of the activities are observing how plastic bags are given in the supermarket or interviewing the public on their awareness of the environment. In the ‘Reflection’ phase, pupils reflect on their experiences by sharing what happened and what is important in their experiences. In the ‘Plan’ phase, pupils relate what they have experienced to their own lives and the real world by making an action plan. In the ‘Apply’ phase, pupils would apply what they have learned to similar or different practical situations.

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**References**

- Brown, Collins and Duguid (1999), Lave and Wenger (1999) and Vahey et al (2005) have been cited in the text, but not provided in the list. Please check.

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- References
3.2 Seamless learning environment

The G1 : 1 working group, comprising of a group of researchers and educators, proposed the idea of SLE where students are able to learn through various scenarios, switching from one scenario to another (Chan et al., 2006). For example, an individual student could be engaged in learning at a park collecting data and images on types of fauna with a mobile device. Later, the student can collaboratively learn with other students by analysing and comparing data they have collected in the mobile devices through online technology at home. Students can continue to be engaged in learning activities across different environments. Some researchers have used mobile devices for students’ seamless learning. For example, the ENLACE project (Verdejo et al., 2006) used mobile technologies to support learning activities from one scenario to another. Lai et al. (2007) enhanced experiential learning by designing a flow of learning activities through the use of mobile devices.

One affordance of mobile devices is its mobility, where students are able to take the device anywhere. The physical space presents a resource for learning through discovery outside the classrooms (Milrad et al., 2004). Mobile technologies enable students to take “mobile, connected and versatile tools into the world” (Swan, Kratcoski and van ’t Hooft, 2007) for learning. Lave and Wenger (1991) argued that learning is contextual and embedded in the social and physical environment. Learning is no longer bounded by the classroom. Students can continue to be engaged informally through the use of mobile technologies even outside the classroom. With network access, artefacts such as data, images or information created on mobile devices flow from one scenario to be shared in different environments. These artefacts can facilitate knowledge construction among a community (Stahl, 2000). The features of mobile devices that store vast amount of information, organise, and present the information can support students’ learning as a cognitive tool (LaJoie and Derry, 1993; Kim and Reeves, 2007). In this study, to help students learn about the environment issues better, they were brought to the supermarket to observe how plastics bags were used, studied types of packaging, and interviewed the public on their attitudes toward and practices of the 3Rs. Using mobile devices, they recorded data on number of plastics bags used, collected information on product packaging, and interviewed the public on their views of conserving the environment. The mobile device application supported the organisation of collected artefacts and provided a structure for the students to follow the learning cycle independently.
4 Learning activity design

Based on the challenge-experiential approach, teachers worked with researchers to design a set of activities that would engage the children in learning the 3Rs and apply those concepts in practice. A group of three teachers started out with the initial learning activity design. The activities were further refined with feedback from larger group of teachers involved in the project. During the design, developers from the Polytechnic were also consulted to align the software development to the learning activities. To provide the pupils with a realistic context for learning about the 3Rs, the activities in the experience phase of the challenge-experiential learning cycle take place in the supermarket. We felt that the pupils were familiar with the shopping in the supermarket, and the location would provide opportunities for them to learn about the 3Rs such as packaging and usage of plastic bags. Interacting with the public on their attitudes toward the 3Rs through the interviews may help the pupils understand the attitudes and practices of others about the 3Rs. This might in turn affect the pupils’ attitudes and behaviours on the 3Rs. Having the activities in the supermarket and interacting with others may provide the pupils with a powerful context for learning through physical environment and social interaction (Lave and Wenger, 1999). Many of the activities were carried out in the classroom, supermarket, fast food restaurant and the school computer lab over a period of two weeks with the technology support such as the pocket PCs, wireless connectivity and an online forum. Prior to the start of the activities, all the students and teachers were trained in the use of the pocket PCs and the application developed for the learning activities. Table 1 shows the designed learning activities.

Table 1

<table>
<thead>
<tr>
<th>Activity</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience – Field activity</td>
<td>Classroom</td>
<td>The teacher gave a short introduction to the problem of having too much garbage. Students created KWL* tables and shared with each other about their learning objectives (1 hour)</td>
</tr>
<tr>
<td>Experience – Field activity</td>
<td>Supermarket and Fast Food Restaurant with wireless network</td>
<td>Three activities that students performed at a supermarket: Studied different sizes and materials for packaging and took photos of the products Observed how many plastic bags were consumed in 5 min. Interviewed customers about their attitudes toward and practices of 3Rs (2 hours)</td>
</tr>
<tr>
<td>Reflecting and Planning – Post-field Activity 1</td>
<td>Computer Lab</td>
<td>Student provided feedbacks to each other’s data collected and posed questions to environmental experts (1 hour)</td>
</tr>
<tr>
<td>Applying – Post-field Activity 2</td>
<td>Classroom</td>
<td>Student groups presented to the whole class about how their groups have designed artefacts for promoting 3Rs ideas and got feedback from the class (1.5 hours)</td>
</tr>
</tbody>
</table>

*K = What I know; W = What I want to know; L = What I learned.
5 Technology design and implementation

5.1 Mobile device software

Studies have shown that mobile devices can be effective instructional tools to support teaching and learning, across curriculum and instruction activities (Vahey and Crawford, 2002). The affordances of the mobile devices such as its small size, running customised applications, wireless connectivity, and integrated camera make it an ideal device for students to collect data, take pictures and transfer the data over the internet outside the classroom. We describe the key components of the mobile device software which supports the designed learning activities and the learning cycle described previously.

5.1.1 Creating a project

The pupil in the group started the activity by creating a project on the mobile device with the software application. All information and data entered by the pupils were stored in a database on the mobile device. The database became a persistent storage for information on the mobile device, letting pupils access, add or edit the information over time. However, this could be a constraint in the deployment as the pupils must use the same mobile device over the duration of the project. Figure 2 shows the project page for the software.

5.1.2 Starting the challenge-experiential cycle

The software was designed according to the challenge-experiential learning cycle. The software let the students to step through the cycle in a structured manner. Clicking on the icons allowed the pupils to branch to different parts of the learning cycle. But, pupils were not allowed to proceed to the next step until they had completed the current step. Figure 3 shows the challenge-experiential cycle on the mobile device.

Figure 2 Creating a project (see online version for colours)
5.1.3 The challenge

In the challenge phase, pupils saw a challenge question and they needed to enter their answers into the answer windows on a mobile device. Figure 4 shows the screen of the mobile device software in the challenge phase.
5.1.4 The experience phase

The experience phase comprised of three activities which pupils were asked to do in the supermarket. The activities are to observe types of packaging in the supermarket, count the number of plastic bags used in the checkout counter and interview the public on their attitudes toward and practices of the 3Rs. Figure 5 shows the screen for the experience phase with the links to the activities. The pupils may choose any activity but must complete all the activities before proceeding to the next phase of the learning cycle.

In Activity 1, pupils chose from one of following categories of food items – milk, biscuits or bread spreads, and recorded the types of packaging used by manufacturers in the chosen category. With the mobile device, they entered information about the packaging and took a picture of the packaging on the mobile device. They were able to annotate on their pictures stored on the mobile device. Figures 6 and 7 show the screen for Activity 1.
In Activity 2, pupils were asked to stand near a supermarket checkout counter to collect data about the usage of plastic bags and the number of people using reusable shopping bags over a span of 5 min. They were asked to estimate the number of plastic bags used during the 5 min observation. Figure 8 displays the screen for Activity 2.

In Activity 3, pupils interviewed the customers in the supermarket to understand their attitudes towards and practices of the 3Rs. Each customer was asked 5 questions one or a couple of students in groups. The pupils read the questions from the mobile device and entered the customers’ answers into the mobile device. The questions asked by the pupils during the interview are in Table 2. Figures 8 and 9 show the screens of the mobile device for Activity 3.
Figure 9  Activity 3 – interviewing the public on their attitudes on the reduce, reuse and recycle (see online version for colours)

Table 2  Interview questions in Activity 3

<table>
<thead>
<tr>
<th>Question</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>Do you bring your own shopping bag when you go to the supermarket?</td>
</tr>
<tr>
<td>Question 2</td>
<td>When you finished using a product, would you purchase a new one or a refill pack? Why?</td>
</tr>
<tr>
<td>Question 3</td>
<td>If shops were to charge 5 cents for every plastic bag, would you bring your own shopping bags?</td>
</tr>
<tr>
<td>Question 4</td>
<td>How often do you recycle your used packaging such as glass or plastic bottles?</td>
</tr>
<tr>
<td>Question 5</td>
<td>Singaporeans should practice reuse, reduce and recycle. Do you agree?</td>
</tr>
</tbody>
</table>

5.1.5 The reflection phase

After the experience phase, the pupils were asked to reflect on their experiences in each of the activity. A list box displayed the activities and indicated if they had completed the reflection with a marked checkbox. Figures 10 and 11 show the screen of the reflection phase for pupils to enter their reflection and a list box of completed reflection for each activity, respectively.

5.1.6 The plan phase

During the plan phase, pupils created plans to apply the 3Rs at home or school. Pupils were aided by prompts such as ‘Our plan is to …’ and ‘The result of my plan is …’ in the description and impact section of their plans, respectively. Figure 12 shows the screen for pupils to enter their plans for the 3Rs in the mobile device.
5.1.7 The apply phase

The pupils entered their plans into the mobile device. Figure 13 shows the screen for pupils to enter the results of applying the 3Rs in practice.

Figure 10 Pupils enter their reflection of their experience in the mobile device (see online version for colours)

Figure 11 Pupils reflect on their experience in each activity (see online version for colours)
Figure 12  Pupils create a plan for applying the reduce, reuse and recycle (see online version for colours)

![3Rs - Plan]

**Activity:** Use Reusable bags  

**Description:**  
- Our question for the expert is ...
- How can we...
- Our plan is to ...

**Impact:**  
- The results of my plan is ...
- To prevent

**Targeted Date:**  
- 12 Aug 2005

![Main Apply >]

Figure 13  Pupils create a plan for applying the reduce, reuse and recycle (see online version for colours)

![3Rs - Apply]

**What are the results after applying your plans? What does mean to you after the experience?**

My family throws the cans in a recycling bin. I did not realize my family throw so much waste into the rubbish. We should have recycle them.

![Main Data]

5.1.8 Generating report and uploading to online forum

Pupils generated a report of all the information and data collected on the mobile device in HTML format shown in Figure 14. The report was directly uploaded to the online forum through the screen shown on Figure 15. Students were asked to enter their username and password for accessing the online forum server. Figure 16 shows the screen for the students to access the uploaded report from the online forum.

AU: Please check the renumbering of the Figures 14 and 15.
Figure 14  Report of the information, data and reflection of pupils generated in the mobile device (see online version for colours)

<table>
<thead>
<tr>
<th>No of Activity</th>
<th>Activity 1</th>
<th>Activity 2</th>
<th>Activity 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of Activity</td>
<td>Product</td>
<td>Brand</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>biscuits</td>
<td>Kraft</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>biscuits</td>
<td>L desper</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>biscuits</td>
<td>Khung gan</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No of Activity</td>
<td>Product</td>
<td>Brand</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Challenge:**
we will have less fresh water, trees and sea creatures will die and more heat will enter the Earth.

**Activity 1**

<table>
<thead>
<tr>
<th>No of Activity</th>
<th>Activity 1</th>
<th>Activity 2</th>
<th>Activity 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of Activity</td>
<td>Product</td>
<td>Brand</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>biscuits</td>
<td>Kraft</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>biscuits</td>
<td>L desper</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>biscuits</td>
<td>Khung gan</td>
</tr>
</tbody>
</table>

**Response to the challenge presented to pupils**

**Data from Activity 1 with pictures taken of packaging**

**Data from Activity 2 on usage of plastic bags**

**Information collected from Activity 3**

**Reflection of students for each activity**

**Plan:**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Date</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A talk about our environment...</td>
<td>11 Nov 2006</td>
<td>increase awareness of importance of the 3Rs</td>
</tr>
<tr>
<td></td>
<td>Our plan is...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Apply:**

<table>
<thead>
<tr>
<th>Date</th>
<th>Reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>People don’t think about the environment...</td>
</tr>
<tr>
<td>2</td>
<td>People don’t care about their environment...</td>
</tr>
<tr>
<td>3</td>
<td>We feel that some students are rude but many...</td>
</tr>
</tbody>
</table>

**Result:**

More people realise what is happening to the earth as the environment is changing.
Designing a seamless learning environment to learn 3Rs

**Figure 15**  Pupils upload the report to the online class portal (see online version for colours)

![Upload interface](image)

**Figure 16**  Accessing the pupils report uploaded from the mobile device on the online discussion forum (see online version for colours)
5.2 Online discussion forum

We designed and implemented an online discussion forum to allow pupils to upload their experiences, reflections, plans, and applications of the 3Rs concepts from the mobile device to a web-based platform. This implementation to a certain extent demonstrated how students could work seamlessly having their data moved across different environment. Pupils can move from mobile environment outside the classroom to online environment in the school computer laboratory. In addition, the social interaction and learning moved from a small group outside the classroom to the group of class pupils in the online environment. The online discussion forum served as a repository for all reports of the pupils uploaded from the mobile devices. It was also a platform for pupils to view the reports of other groups, post questions and exchange opinions. Figure 17 shows a screen shot of the online forum with the pupils reports uploaded from the mobile device over a wireless connection. The discussion board engaged the students in generating and processing information (Markel, 2001), through which they constructed knowledge. In addition, students could post questions to the teachers or experts at the National Environmental Agency (NEA) on specific issues on the 3Rs.

6 Evaluation

Eighty one fourth grade students from two classes in a Singapore school were observed for this study. Data were collected to capture student understandings through the learning activities. Pre- and post-activity tests were conducted among the students to find out if
they had gained better understanding of the 3Rs concepts. Target students were interviewed at the end of the activities to understand what they had learned about 3Rs and how they practiced 3Rs. In addition, we examined the reports generated by each group’s pocket PC, KWL charts created by the students and the questions posted on the online forum by the students. These artefacts may offer a glimpse in better understanding the learning outcomes.

6.1 Students’ understanding of reduce, reuse and recycle

In the pre- and post-tests, the students were asked to what extent they know about the 3Rs. Table 3 shows positive outcomes in the students’ self-reported knowledge on 3Rs after the activity. There was an increase of 16% in the number of students reporting they know the 3Rs in details while there was a decrease of 12.3% in the number of students who ‘do not know the details’.

To validate the results of the students’ self reported knowledge on the 3Rs, they were asked open-ended questions on their understanding of 3Rs. They had to define what each of the term meant and gave examples for each term. A sample question was “What do you understand by Reduce? Please give examples to explain”. A score on a scale of 0–3 was given to each definition and example based upon a coding scheme that was designed and agreed upon by the researchers. Cohen’s Kappa was used to measure the inter-reliability of the data coded independently by two researchers. The Cohen’s Kappa was 0.68 for the concept and 0.69 for the example, which indicated fair to good agreement between coders. Tables 4 and 5 describe the results of the students on the open-ended questions.

Paired-sample *t* tests were employed to compare the understanding of the 3Rs before and after the field activities (Table 6). The results showed there was a significant improvement in the student’s conceptual understanding of reduce and recycle and number of examples provided for 3Rs.

Below (Table 7) are samples of the students’ answers to the open-ended questions on what they understood about 3Rs on the pre- and post-tests. Pre-test responses revealed that students had heard about the 3Rs, but their understandings were vague and often confusing. For example, they confused recycle with reuse as shown below. The post-test showed that pupils showed better understanding of the terms and gave better examples.

**Table 3** Descriptive analysis of the extent to which the student know about reduce, reuse and recycle (*N* = 81)

<table>
<thead>
<tr>
<th></th>
<th>Never heard of it.</th>
<th>Heard of it, but do not know what it exactly is.</th>
<th>Know what it is, but do not know the details.</th>
<th>Know the details about it.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>1</td>
<td>5</td>
<td>21</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>1.2%</td>
<td>6.2%</td>
<td>25.9%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Post-test</td>
<td>0</td>
<td>3</td>
<td>11</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>3.7%</td>
<td>13.6%</td>
<td>82.7%</td>
</tr>
</tbody>
</table>
Table 4  Descriptive analysis of open ended questions in conceptual understanding of the reduce, reuse and recycle (N = 81)

<table>
<thead>
<tr>
<th></th>
<th>No idea</th>
<th>Vague idea</th>
<th>Partial</th>
<th>Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Pre-test</td>
<td>20</td>
<td>13</td>
<td>48</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>24.7%</td>
<td>16%</td>
<td>59.3%</td>
<td>–</td>
</tr>
<tr>
<td>Post-test</td>
<td>5</td>
<td>12</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6.2%</td>
<td>14.8%</td>
<td>79%</td>
<td>–</td>
</tr>
<tr>
<td>Reuse Pre-test</td>
<td>10</td>
<td>12</td>
<td>57</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>12.3%</td>
<td>14.8%</td>
<td>70.4%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Post-test</td>
<td>8</td>
<td>4</td>
<td>66</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>9.9%</td>
<td>4.9%</td>
<td>81.5%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Recycle Pre-test</td>
<td>49</td>
<td>2</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>60.5%</td>
<td>2.5%</td>
<td>27.2%</td>
<td>9.9%</td>
</tr>
<tr>
<td>Post-test</td>
<td>25</td>
<td>5</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>30.9%</td>
<td>6.2%</td>
<td>49.9%</td>
<td>13.6%</td>
</tr>
</tbody>
</table>

Table 5  Number of correct examples given by of the reduce, reuse and recycle (N = 81)

<table>
<thead>
<tr>
<th>Number of examples</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Pre-test</td>
<td>25</td>
<td>49</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>30.9%</td>
<td>60.5%</td>
<td>7.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Post-test</td>
<td>9</td>
<td>66</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11.1%</td>
<td>81.5%</td>
<td>4.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Reuse Pre-test</td>
<td>24</td>
<td>54</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>29.6%</td>
<td>66.7%</td>
<td>2.5%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Post-test</td>
<td>10</td>
<td>69</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>12.3%</td>
<td>85.2%</td>
<td>2.5%</td>
<td>0%</td>
</tr>
<tr>
<td>Recycle Pre-test</td>
<td>70</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>86.4%</td>
<td>13.6%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Post-test</td>
<td>51</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>63%</td>
<td>37%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 6  Paired-sample t test of students understanding on reduce, reuse and recycle (N = 81)

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Concept</td>
<td>1.35</td>
<td>1.73</td>
<td>–3.420*</td>
</tr>
<tr>
<td>Example</td>
<td>0.79</td>
<td>0.99</td>
<td>–2.551**</td>
</tr>
<tr>
<td>Reuse Concept</td>
<td>1.63</td>
<td>1.79</td>
<td>–1.604</td>
</tr>
<tr>
<td>Example</td>
<td>0.75</td>
<td>0.90</td>
<td>–2.039**</td>
</tr>
<tr>
<td>Recycle Concept</td>
<td>0.86</td>
<td>1.46</td>
<td>–4.038*</td>
</tr>
<tr>
<td>Example</td>
<td>0.14</td>
<td>0.37</td>
<td>–3.811*</td>
</tr>
</tbody>
</table>

Note: *p < 0.01; **p <0.05.
### Table 7: Responses to open-ended questions on the understanding of the reduce, reuse and recycle in pre- and post-tests

<table>
<thead>
<tr>
<th>Area</th>
<th>Student</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycle</td>
<td>Student 1</td>
<td>Recycle means to make something old into a new thing</td>
<td>It means to make an old thing into a new one throughout a process. Make old newspaper into plan papers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paper</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Newspaper</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Student 2</td>
<td>I make use of something and make another thing. I use newspapers to make origami and display it in my house</td>
<td>It means to make use of something that is unwanted or used to make another new product. Using old newspapers to make into new white paper</td>
</tr>
<tr>
<td></td>
<td>Student 3</td>
<td>Give newspaper to the newspaper man</td>
<td>Recycle means transforming something not in use to something better. Newspaper can be recycled to form paper</td>
</tr>
<tr>
<td></td>
<td>Student 4</td>
<td>Reduce means to use less to me. Use a pail to wash the car.</td>
<td>Reduce means cut down of using things. Use reusable bags instead of plastic bags</td>
</tr>
<tr>
<td></td>
<td>Student 5</td>
<td>Reduce means try not to use much. Like reduce littering on the floor.</td>
<td>It means cut down. Reduce using plastic bags</td>
</tr>
<tr>
<td>Reuse</td>
<td>Student 6</td>
<td>Reuse means to use again. Like to use the water after you use it to wash clothes</td>
<td>It means to use again for the same or other purpose. To use the same plastic bags or bottles again</td>
</tr>
</tbody>
</table>

### 6.2 Application of reduce, reuse and recycle

At the end of the activity, each group presented a plan on how they would practice 3Rs in their home and school using posters and Power Point presentations. Samples of the posters are shown in Figures 18 and 19 below. Students had demonstrated correct use of 3Rs as shown below.

**Figure 18:** Students’ understanding of materials and recycling (see online version for colours)
In-depth interviews were conducted to examine how the students practiced 3Rs at home. The results from the interviews revealed that the students did talk to their parents about the environment to influence them in conserving the environment. As shared by one of the students,

“My family does not actually use reusable bags. It is always my mom who does shopping. Yesterday I told my father you should use and can always encourage my mom to use more reusable bags. He agreed with it and then he said that but sometimes we have a lot of things so we need to have some plastic bags to use. Sometimes we can keep these plastic bags.”

One student talked about the recycling plan: “At home we use a mineral water bottle, we cut out… put a paint brush inside there that I can use that one to paint.” Another two students mentioned the change of their parents’ shopping habit: “They will bring reusable bags when they are shopping. They didn’t not do it before”; “They recycle plastic containers now!”

7 Conclusions and discussion

This study showed positive learning outcomes of the designed activities supporting by mobile devices. A parallel study conducted in another 3Rs project schools showed similar learning outcomes (Zhang, et al., 2006). Our results showed that students’ understanding of the 3Rs improved and many of them practiced 3Rs at home and school. A challenge-experiential approach was useful in engaging the students to learn about the 3Rs. It provided rich experience for the students to understand the concepts and internalise the concepts through reflection, planning and application. The use of technology such as mobile devices, wireless network, and online collaborative discussion forums provided students the opportunity to learn in a ‘seamless learning’ environment where they moved between one scenario and another. We realised that the learning occurred not only through the use of the technology, but also through the classroom activities that were designed to engage the students. The current design and learning outcomes in this study
enabled us to design better learning activities and environments. For example, students probably needed more scaffolds to engage students in online sharing and critiquing.

### 7.1 Improving contextual learning in the activities

When analysing the reflection, plans, application and questions asked by the pupils, we observed most of pupils learn about the 3Rs in the context of the plastic bag usage more as compared to packaging. We realised that the activities designed in the context of plastic bags, i.e. observing the check out counter and interviewing the public on plastic bag usage, probably left a greater impact on the experience of the pupils. This experience would lead to a transformation of knowledge on the 3Rs. The design of activities to observe different types of packaging did not achieve a significant improvement in their understanding about the 3Rs. The students’ reflections often showed that they noticed the type of material used in the packaging, but failed to go beyond to understand how some manufacturers excessively over package their products to create wastage. There could be due to a few reasons. First, pupils did not have much time to observe the different types of packaging. When examining the reports generated by the students, we found that some groups had only one or two packaging items with pictures. Second, pupils did not seem to observe in greater detail the various types of packaging used for an item. For example, some jam spread manufacturer used three different materials, e.g. plastic, glass and paper in their packaging. Despite the implementation of tools to annotate images of packaging, pupils seldom utilised this feature to record what they observed in detail which may indicate their lack of detailed observation. Third, collecting numerical data such as the number of plastic bags and reusable bags used supported a deeper understanding on how 3R impacts the environment than just comparing types of packaging. Improvement could be made to allow more time in this activity by training pupils to learn what to observe and reflect on the different types of packaging manufacturers used. Thus, it is important to consider the context of the design of the mobile learning activities to achieve the behaviour and cognitive objectives (Uden, 2006).

### 7.2 Data modelling using mobile devices and online technologies

Using data modelling as an inquiry process, students can learn to “solve real problems and answer authentic questions” (Hancock, Kaput and Goldsmith, 1992, p.337). Data creation and data analysis forms two halves of the data modelling process. The data creation process involves deciding what data to collect, how to organise and categorise the collected data. In data analysis, students required to interpret the data through visual representations like graphs, recognise patterns and draw conclusions from the data. Student use of mobile device can support the data creation process in collecting and categorising data. For example, in the 3Rs project students collected data on the number of plastic bags used and number of people who practice recycling at home by entering the information into the mobile devices. Aggregating the data collected on each mobile device may provide student opportunities to analyse the data and draw their own conclusion on how many plastic bags were used in a typical day at the supermarket. A possible extension to this project is to allow students to upload their collected data from the mobile device to a central database. During the lab activities, students could view visual and tabular data representations of their own, other students and whole class using a web browser to query the central database. Students acquire data literacy skills when
they interpret information from the data, use the data as evidence to support their thinking, evaluate data from different sources, and communicate their solution using data (Vahey et al., 2005). Using mobile technologies to collect data offers opportunities for students to be engaged in a realistic interdisciplinary context for understanding and solving problems through data analysis.

7.3 Better classroom collaboration through the online platform

Although the use of an online discussion forum was designed in the activity less collaborative activity was observed among the students as compared to direct face-to-face collaboration. This can be attributed to the lack of time pupils had in reviewing the project reports of other groups and participating in the online discussion. Schwartz et al. (1999b) argues that learning can be more effective through learning communities where people collaborate to achieve an objective and having access to expertise outside the classroom. Time might be too short to form an online learning community comprising of experts from NEA to interact with the pupils to discuss about the environmental issues. We may encourage the students to access the online forum and participate in the online discussion from their home if they have a computer. The usage of the discussion forum can be increased to allow interaction between pupils, teachers and experts from the NEA.

7.4 A framework of understanding learning in a seamless learning environment

Though our design of the seamless environment showed students’ some learning gains in the 3Rs, we have yet to fully understand how the learning outcomes occur. The theory of distributed cognition (Salomon, 1993; Hollan, Hutchins and Kirsch, 2001; Pea and Maldonado, 2006) may provide a framework to study how these learning outcomes occur in a SLE. The learning outcomes could occur as a result of using technology as mediating tools over activities, artefacts and people distributed over time and space. Understanding how learning occurs in students through interaction with technology over activities, artefacts and people may help to design SLE to improve learning outcomes.

Acknowledgements

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References

Designing a seamless learning environment to learn 3Rs


